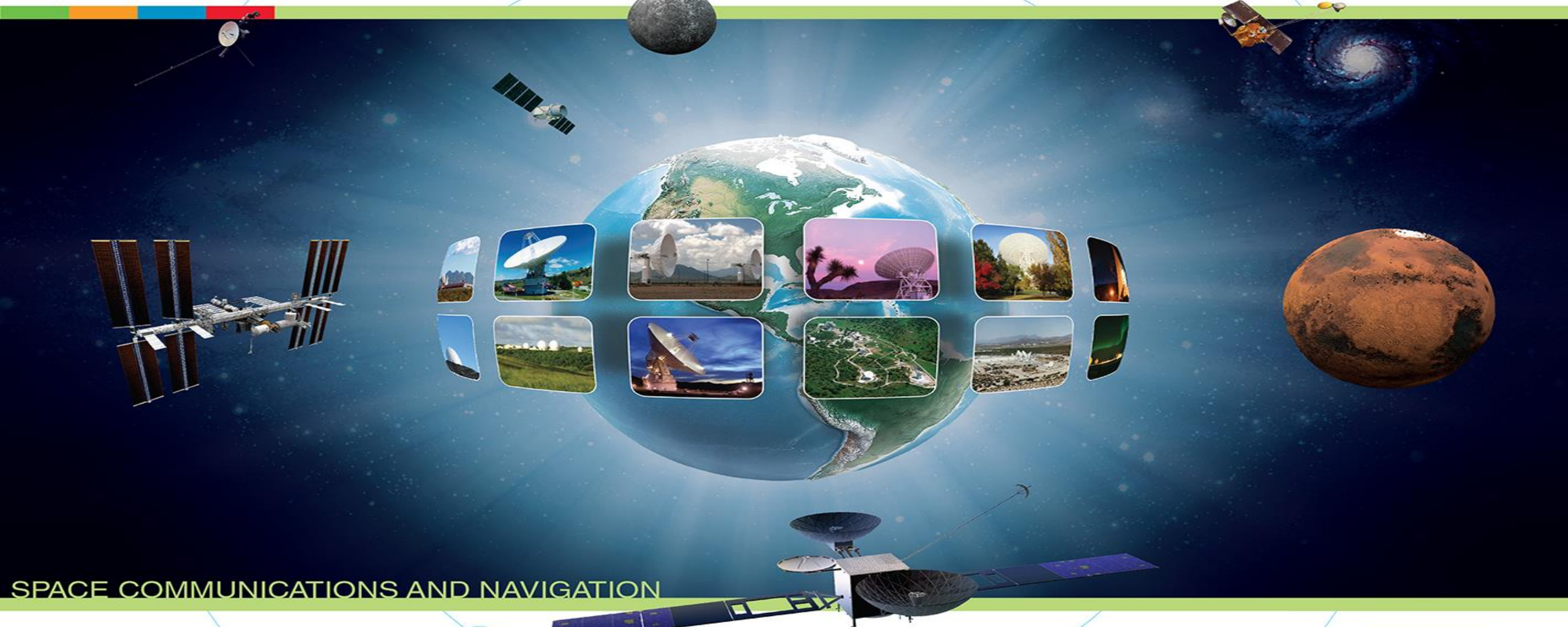




The University of Puerto Rico, Mayagüez  
Campus - College of Engineering

National Aeronautics and  
Space Administration



## SPACE COMMUNICATIONS AND NAVIGATION

### Reconfigurable Wideband Circularly Polarized Stacked Square Patch Antenna for Cognitive Radios

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Seth W. Waldstein, University of Cincinnati

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June 28<sup>th</sup> 2017





# Outline



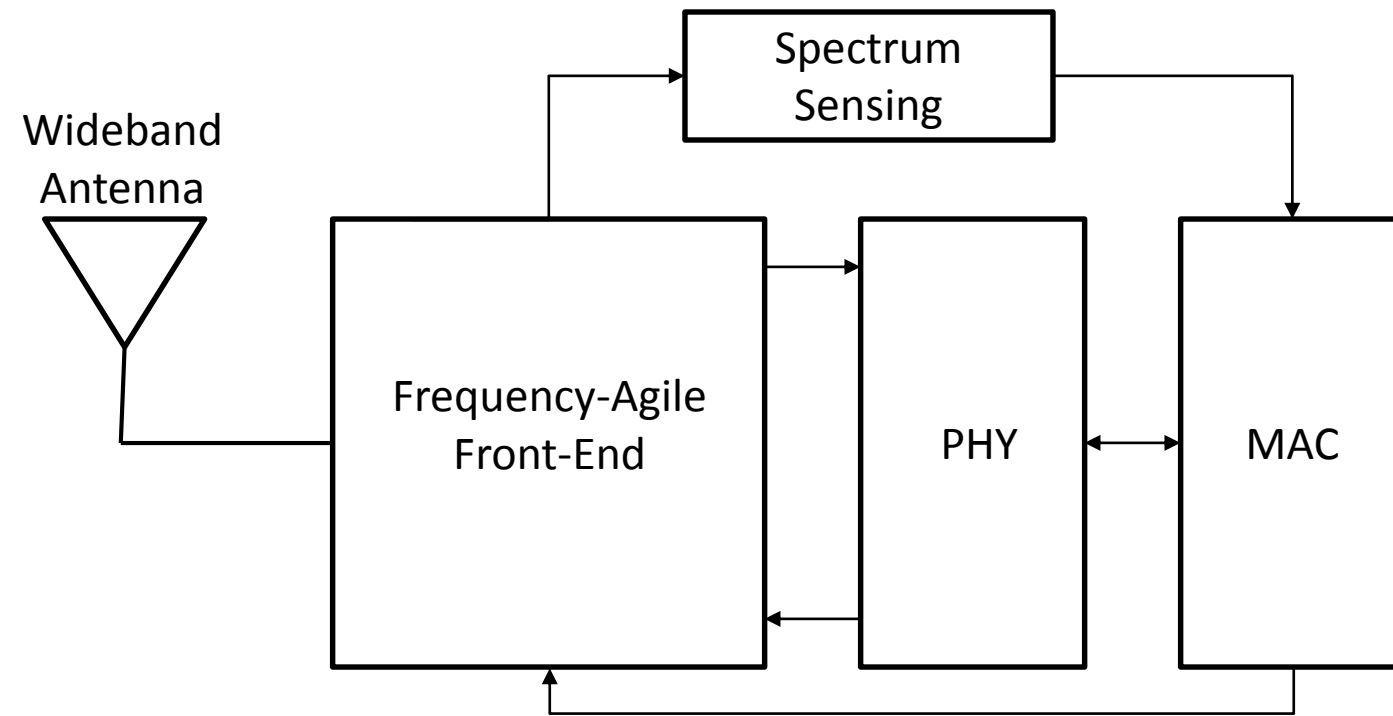
- Introduction
  - Motivation
    - Cognitive Radio
    - Advantages
- Desired Features of Cognitive Radio
  - Antenna Reconfiguration Advantages
- Antenna Design and Modeling
  - Standalone Geometries
  - Stacked Geometry
- Fabrication and Characterization
- Summary of Results
- Future Work
- Conclusion
- Acknowledgements



# Objective



- Design a microstrip patch antenna element for Cognitive Radios for frequency reconfiguration at NASA X-Band frequencies (8.0 – 8.5GHz)



- Advantages of Cognitive Radios
  - It has knowledge of external environment
  - Can use this knowledge to exploit internal parameter tuning (carrier frequency, transmit power, etc.)
- Software Enabled Reconfiguration
  - Frequency-Agile Front-End module
  - Physical Layer Signal Processing (PHY)
  - Medium Access Control (MAC)
- Physical Layer
  - Wideband antennas are required
  - Conventional microstrip patch antennas are narrowband
  - Hence, antenna reconfiguration is desirable

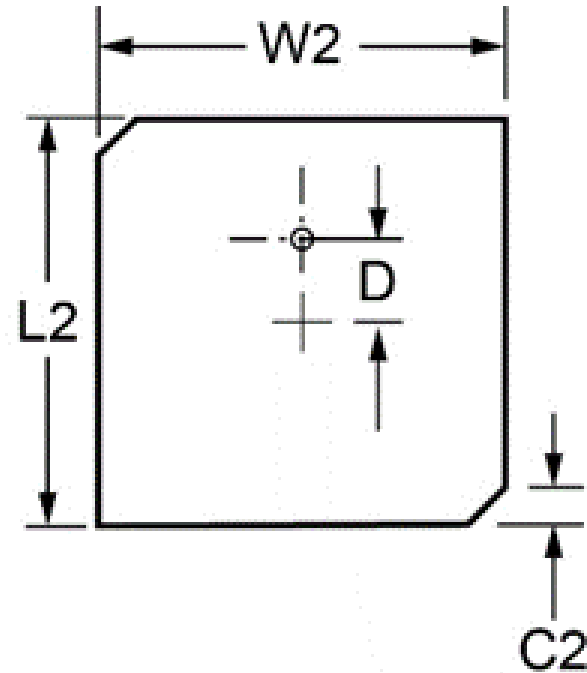
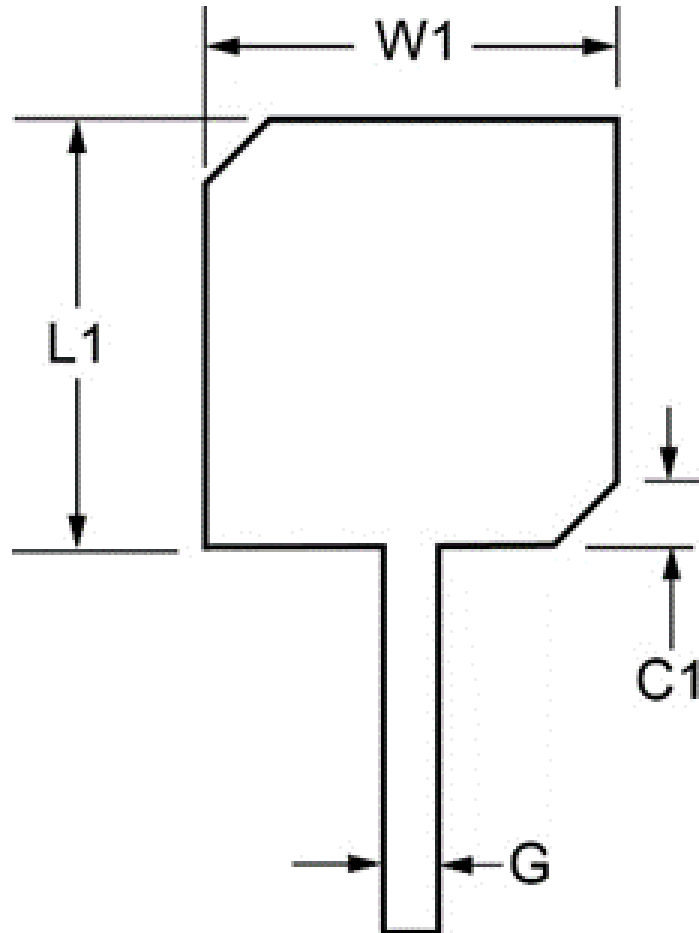
\*J. Laskar, R. Mukhopadhyay, Y. Hur, C. -H. Lee, and K. Lim, "Reconfigurable RFICs and Modules for Cognitive Radio," 2006 Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems, San Diego, CA, 18-20 Jan. 2006.



# Antenna Reconfiguration



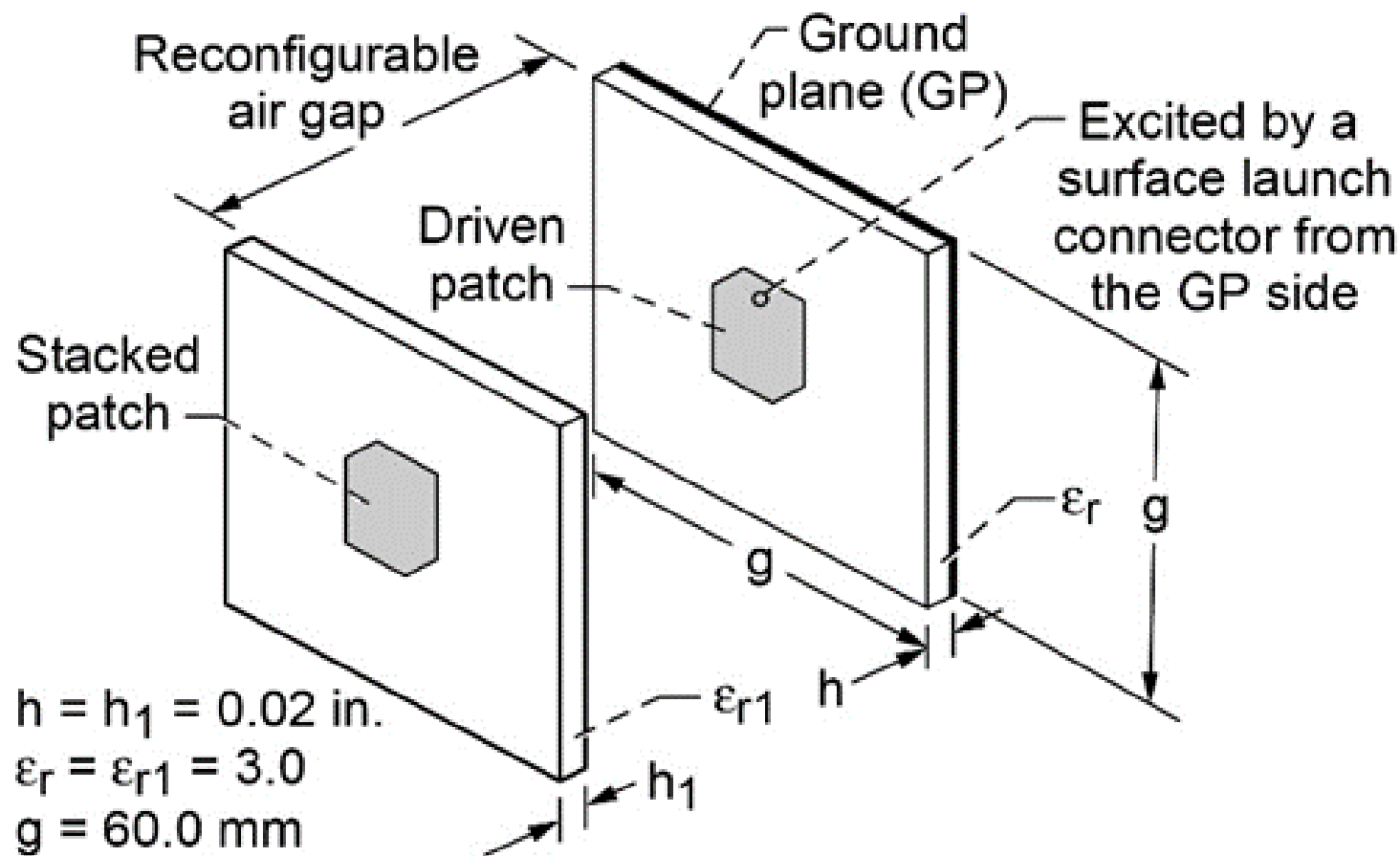
- The Microstrip Patch Antenna
  - It is lightweight, easy to fabricate and has a low cost
  - These features make fast prototyping feasible
  - Its biggest downside is narrow bandwidth
- Microstrip Patch Antennas have the potential for reconfiguration in frequency, polarization and radiation pattern
- They can further expand the added reconfiguration capabilities of the physical layer in a Cognitive Radio



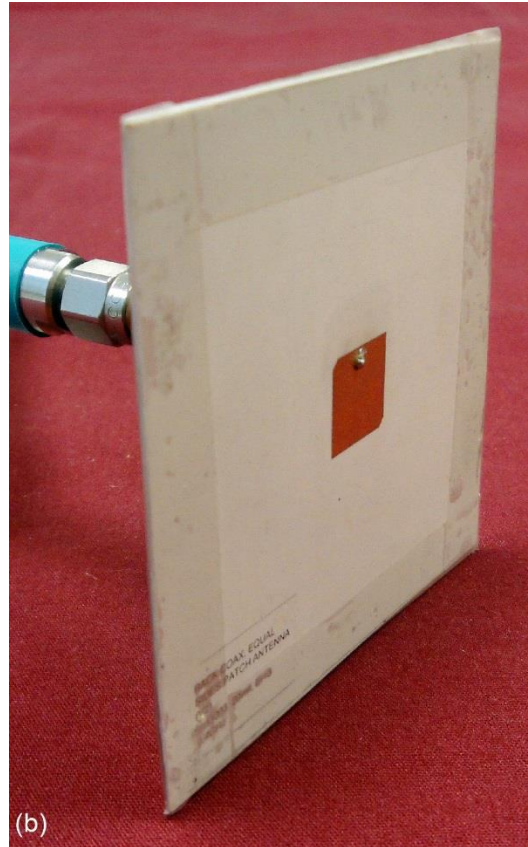
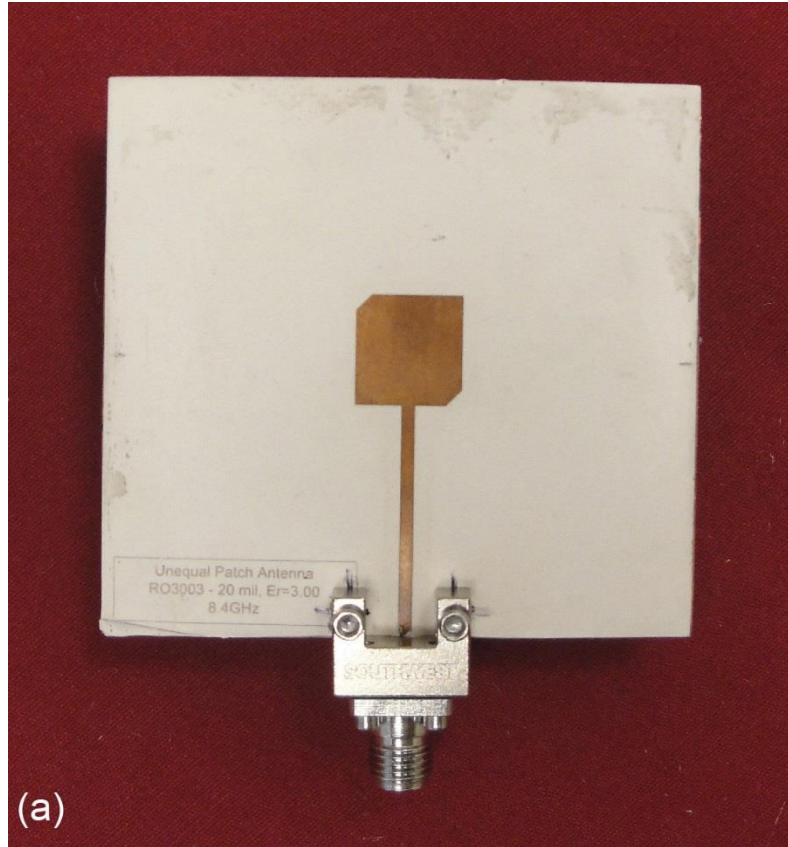
Dimensions (mm)	
$L_1$	10.337
$W_1$	10
$C_1$	1.487
$G$	1.277
$L_2$	9.856
$W_2$	9.856
$C_2$	0.873
$D$	2



# Stacked Square Patch



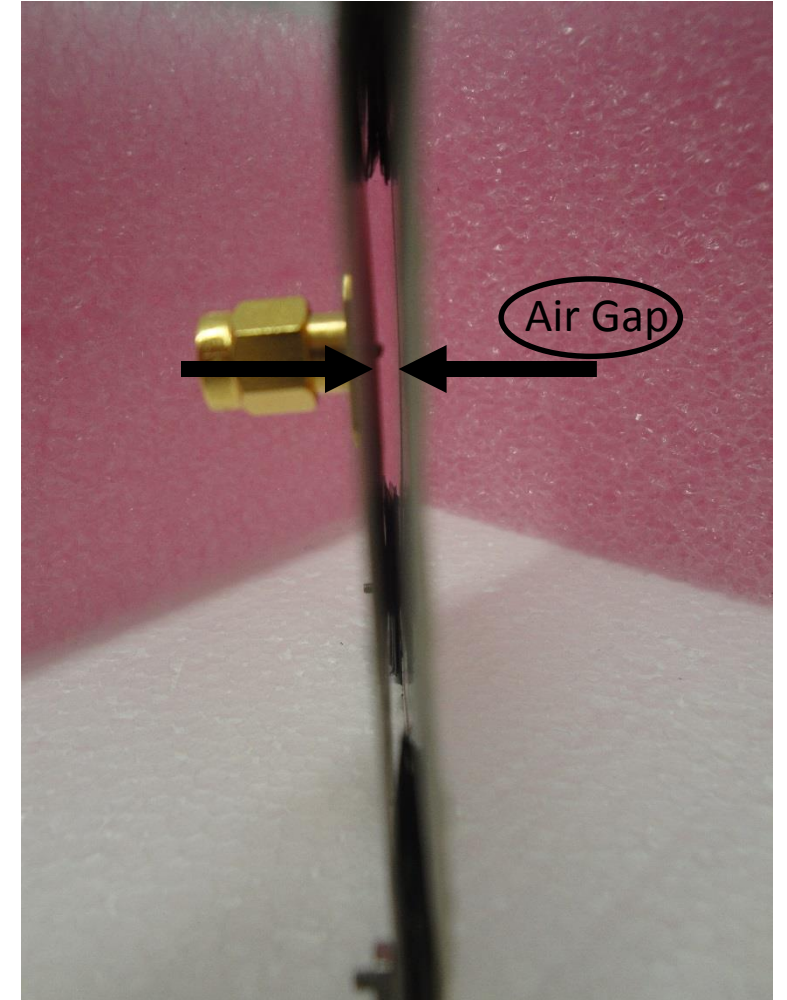
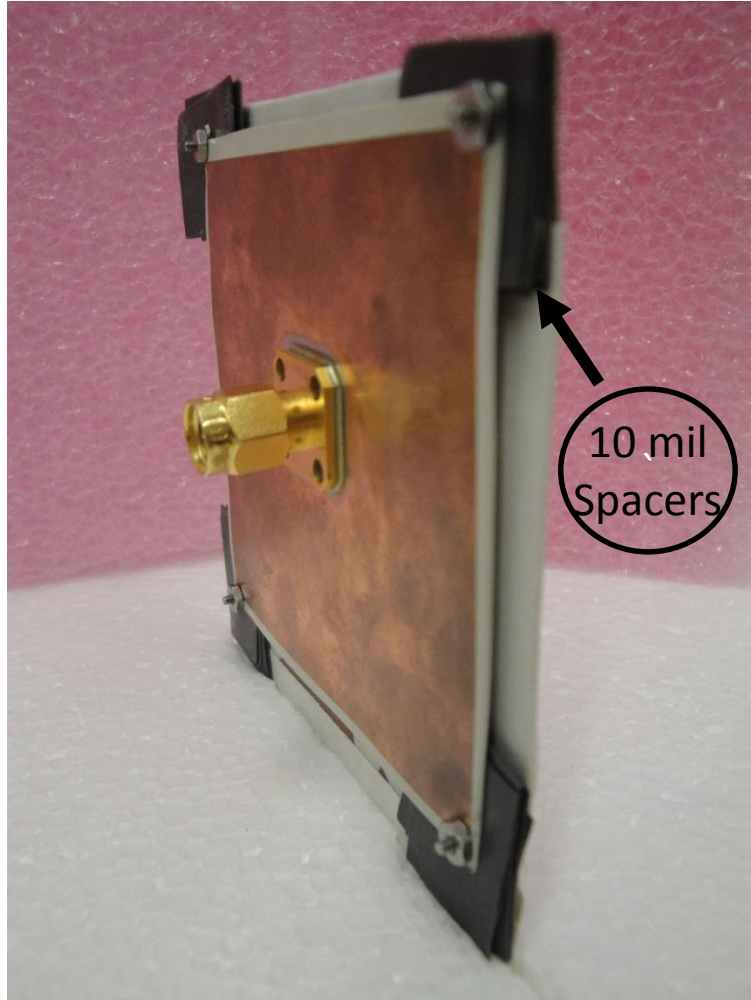
- Identical antenna geometry and substrate properties
- No ground plane on the second substrate
- Fixed 0.254 mm initial air gap between both substrates



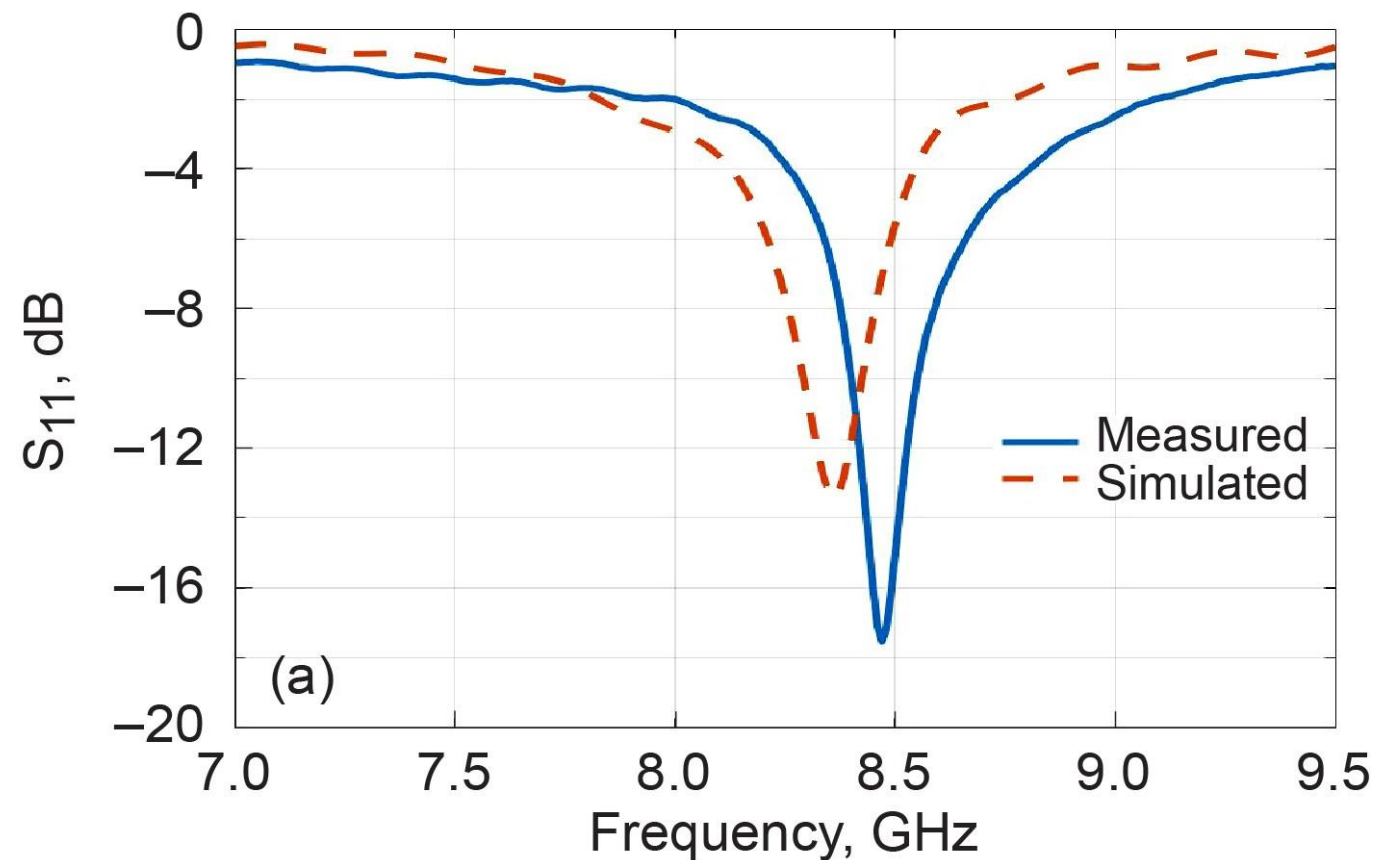
- The CST designs were exported to AutoCAD for the creation of a mask
- The antennas were fabricated using a photolithography process at NASA Glenn Research Center
- Roger's Corporation RO3003 Substrate
  - $h = 20 \text{ mil (0.508 mm)}$
  - $\epsilon_r = 3$



# Stacked Square Patch



# Standalone Almost Square Patch



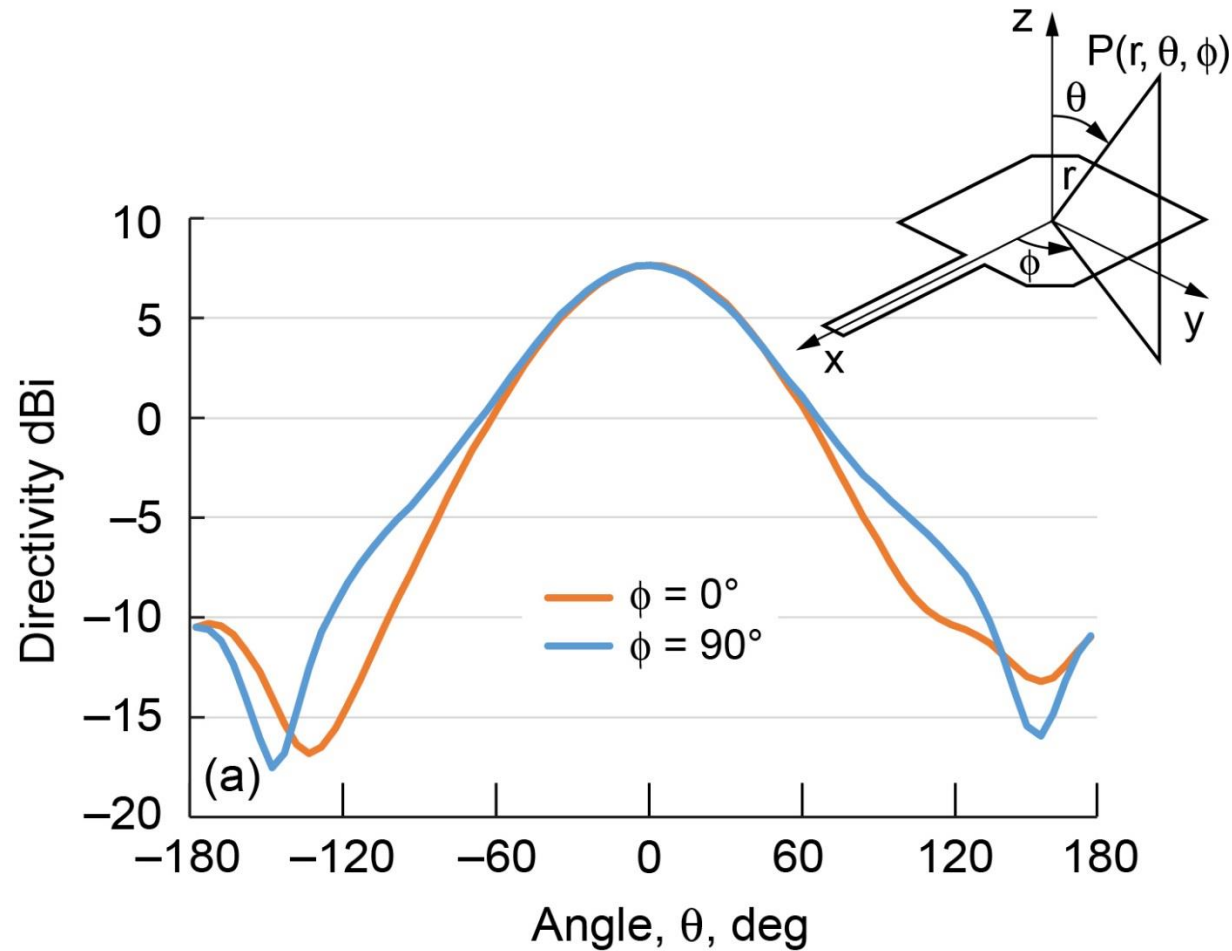
## CST SIMULATED RESULTS

$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.356	13.460	8.2888	8.4203	131.5	1.57

## MEASURED RESULTS

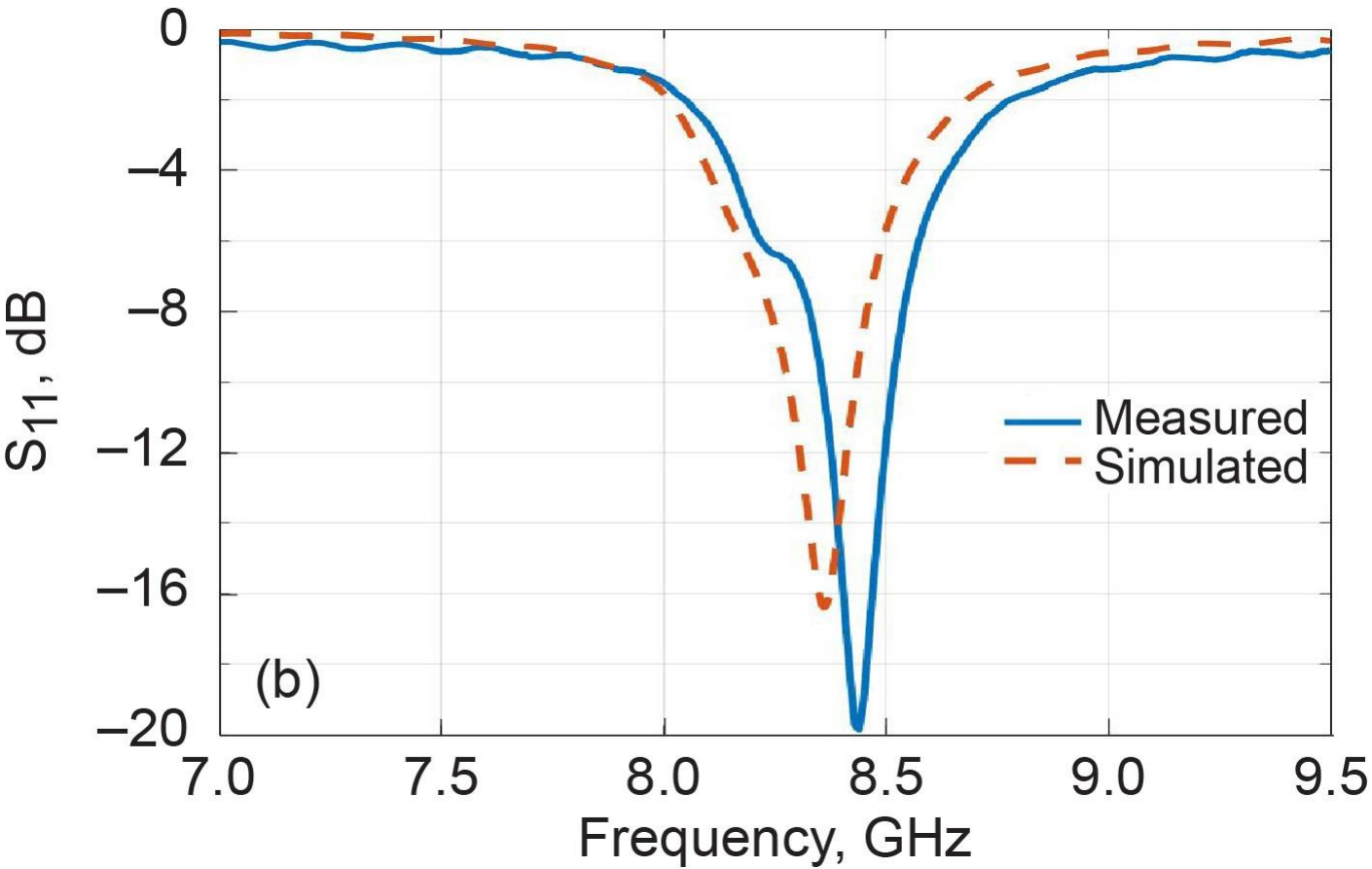
$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.46	17.5402	8.385	8.529	144	1.7

# Standalone Almost Square Patch



CST SIMULATED RESULTS			
	Directivity (dBi)	Realized Gain (dB)	3 dB Angular Width (Deg.)
Phi = 90	7.65	6.7	76.4
Phi = 0	7.65	6.7	75

# Standalone Square Patch



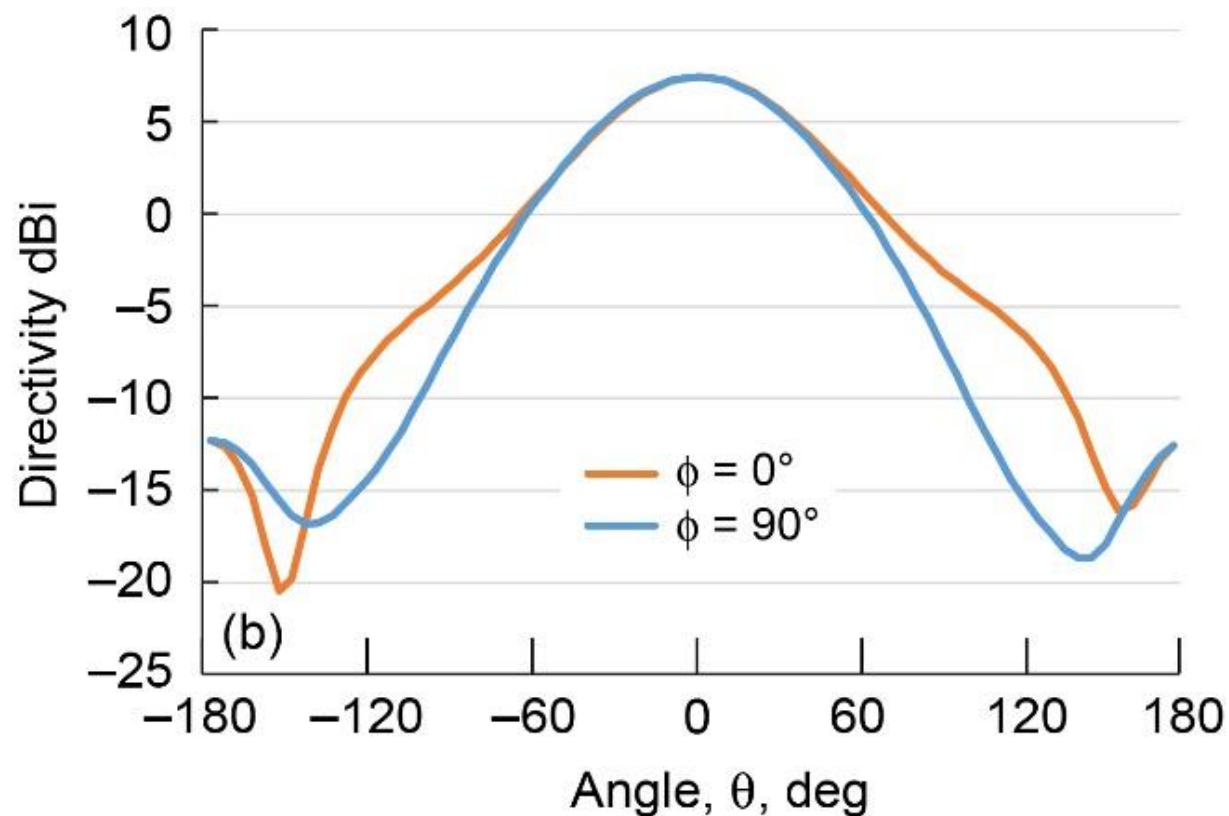
## CST SIMULATED RESULTS

$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.364	16.375	8.2797	8.4314	151.7	1.81

## MEASURED RESULTS

$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.45	19.7545	8.3675	8.5255	158	1.87

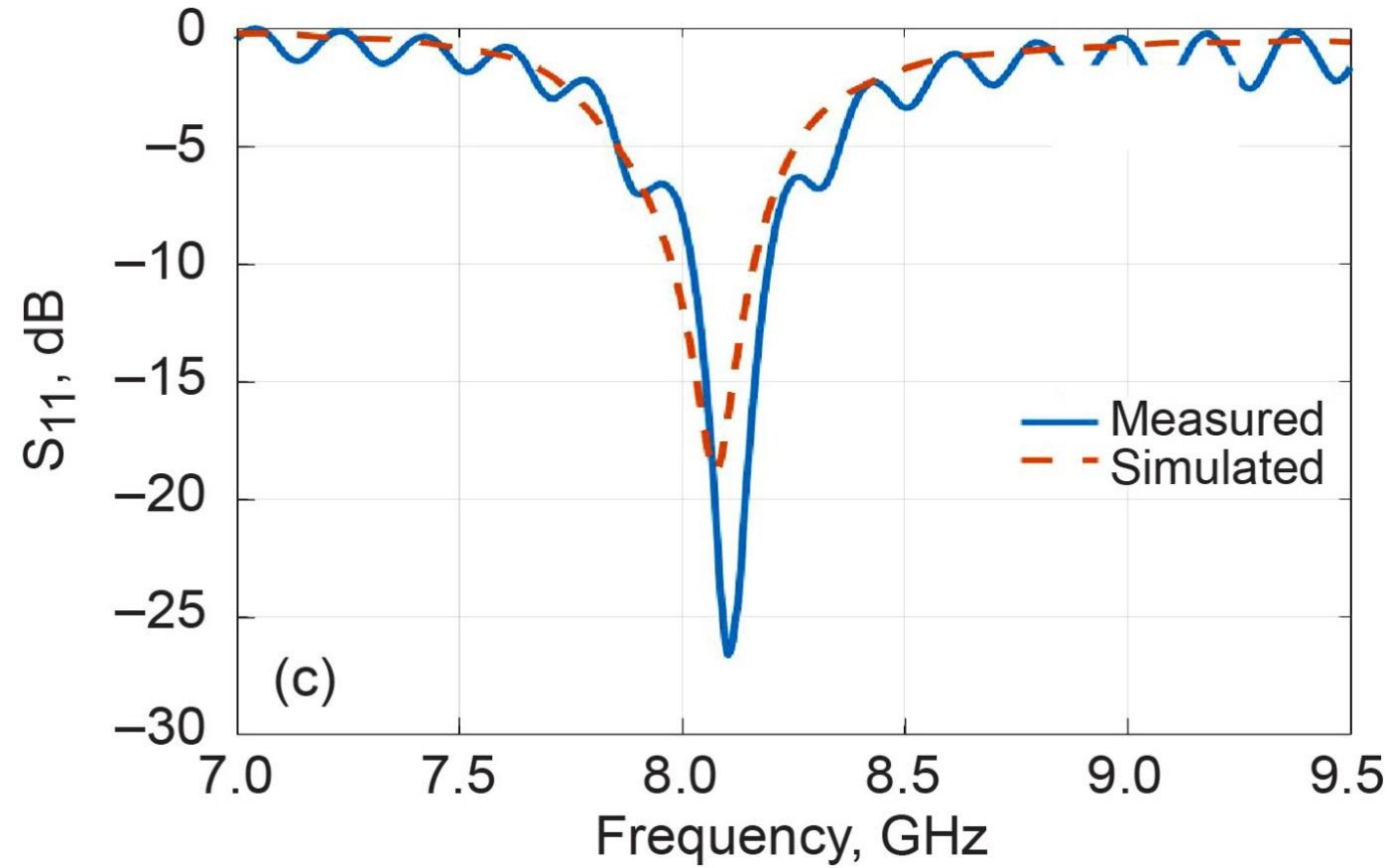




CST SIMULATED RESULTS			
	Directivity (dBi)	Realized Gain (dB)	3 dB Angular Width (Deg.)
Phi = 90	7.45	6.75	76.6
Phi = 0	7.45	6.75	77



# Stacked Square Patch



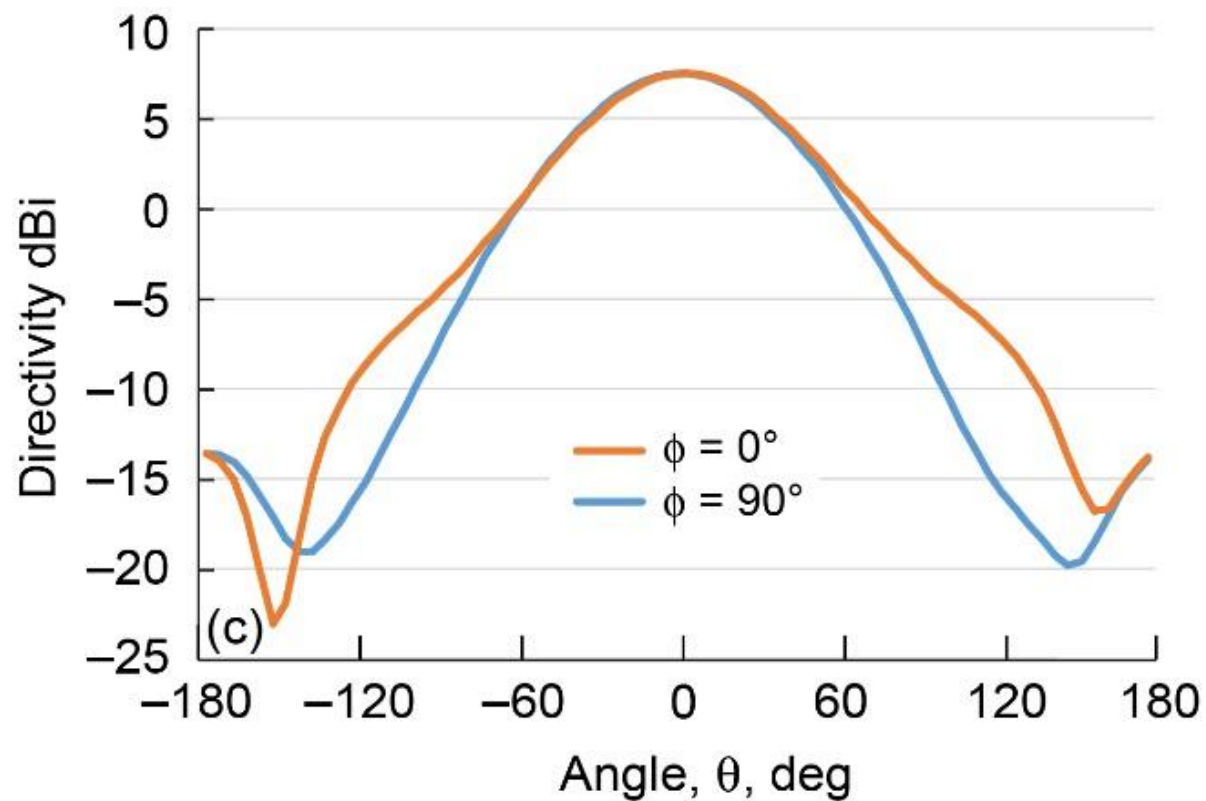
**CST SIMULATED RESULTS**

$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.076	18.869	7.9755	8.1625	187	2.31

**MEASURED RESULTS**

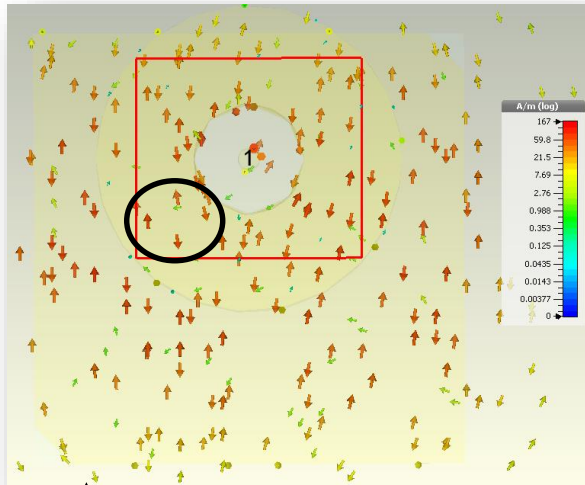
$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	BW = $f_H - f_L$ (MHz)	BW/ $f_0$ (%)
8.1017	25.7	8.0204	8.2005	180.1	2.22

# Stacked Square Patch

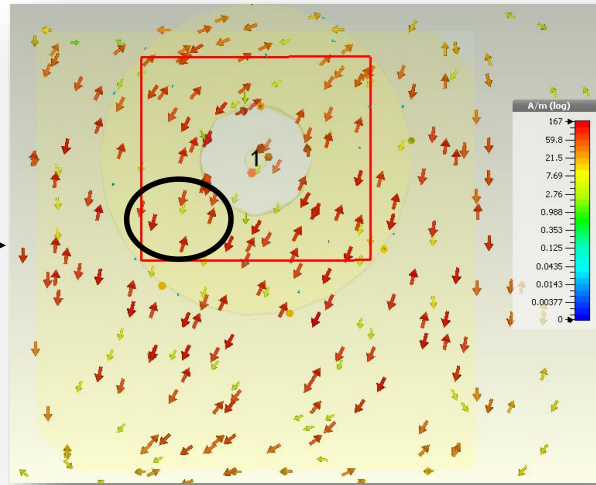


CST SIMULATED RESULTS			
	Directivity (dBi)	Realized Gain (dB)	3 dB Angular Width (Deg.)
Phi = 90	7.53	7.1	76.1
Phi = 0	7.53	7.1	76.7

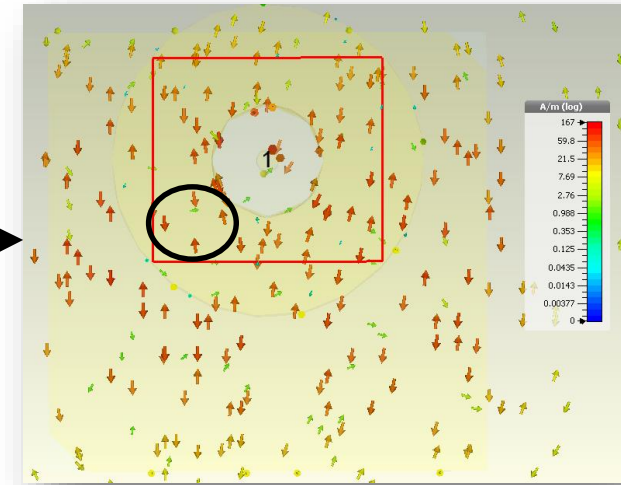
# Simulated Surface Currents



Phase = 0



Phase = 90



Phase = 180



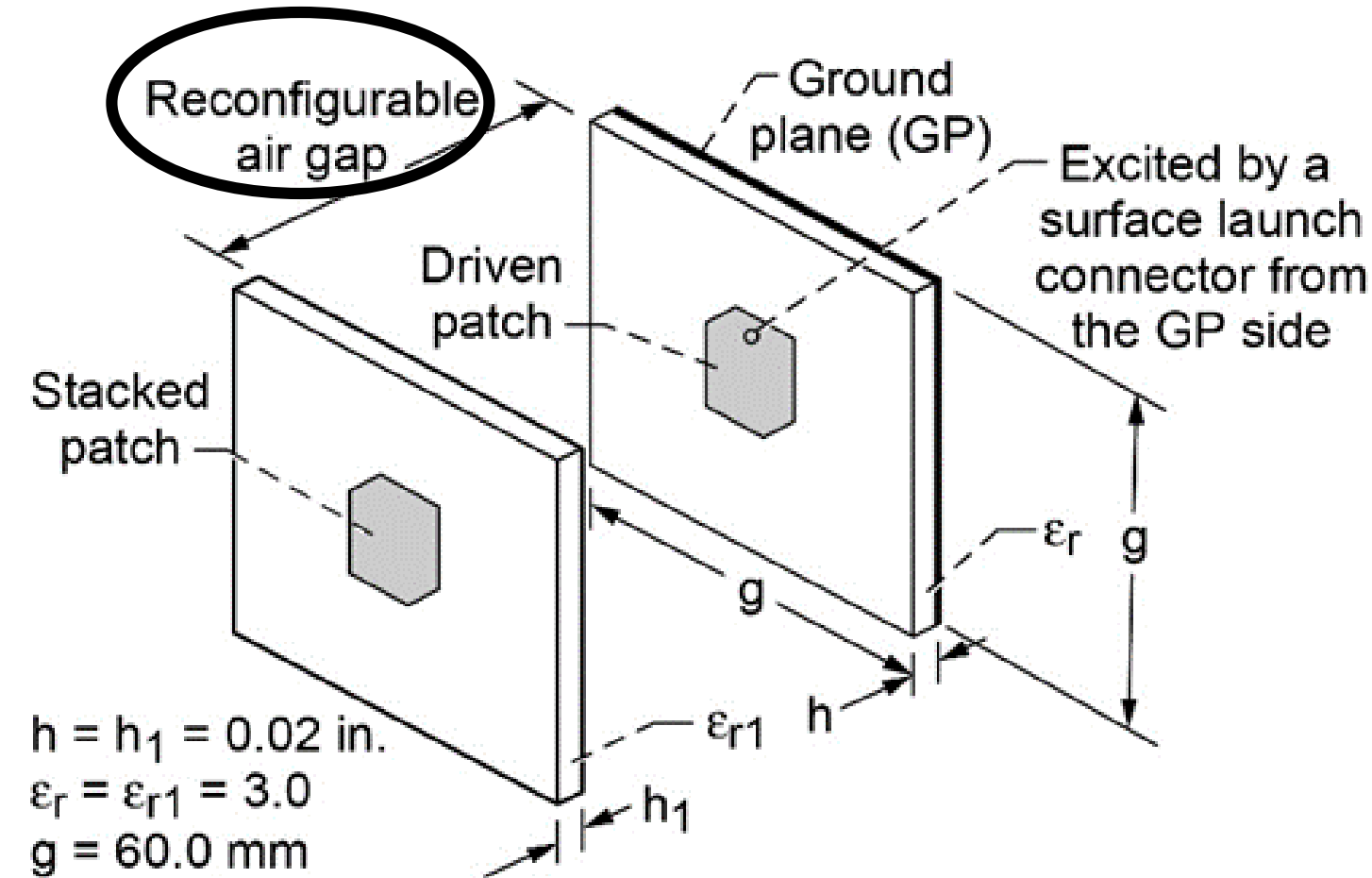
Phase = 270

- When looking through the feed side, the surface currents show a counter clock wise pattern
- This proves LHCP through simulation



- Set up of microstrip patch antenna with a LHCP reference spiral antenna to prove polarization
- A LHCP signal was received from the spiral antenna

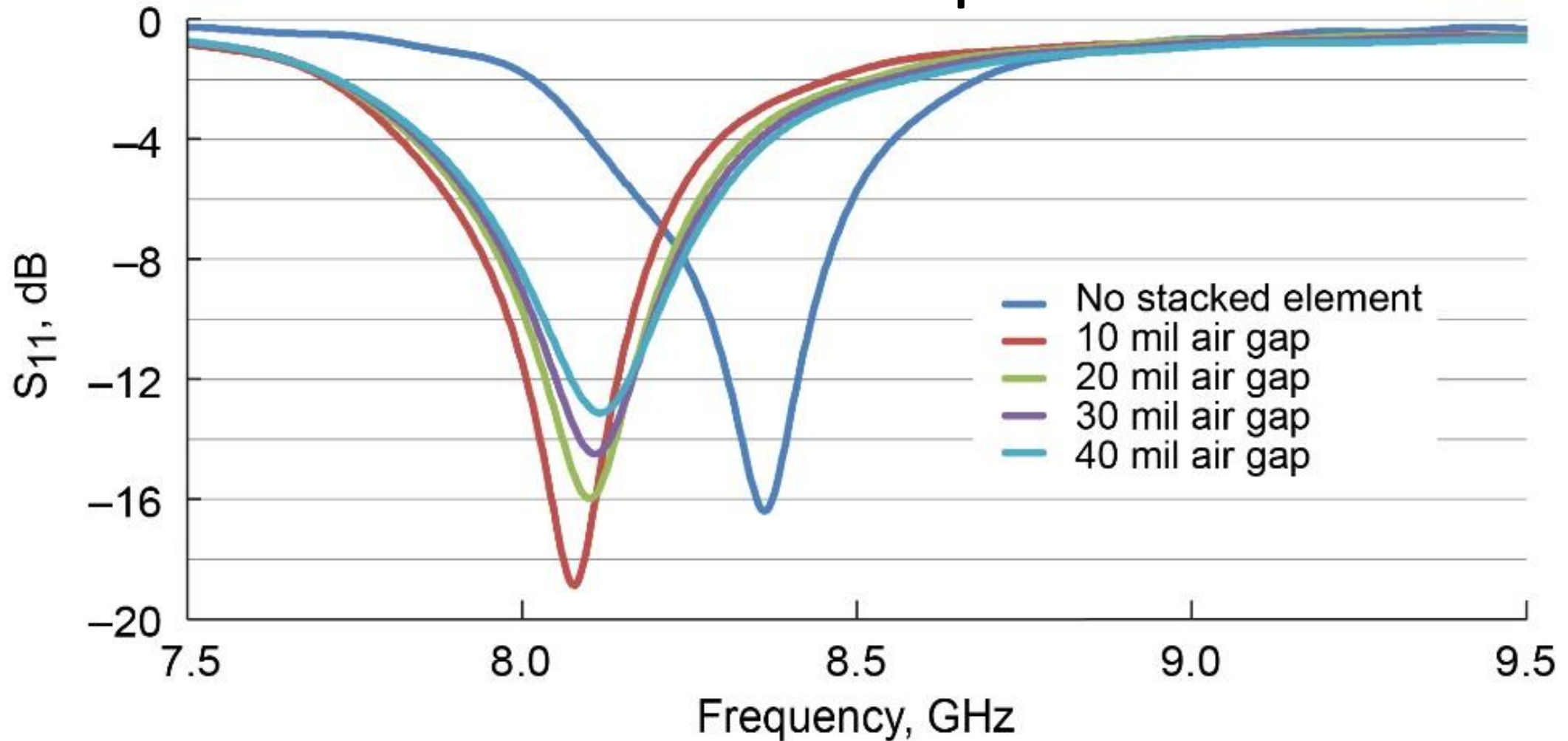




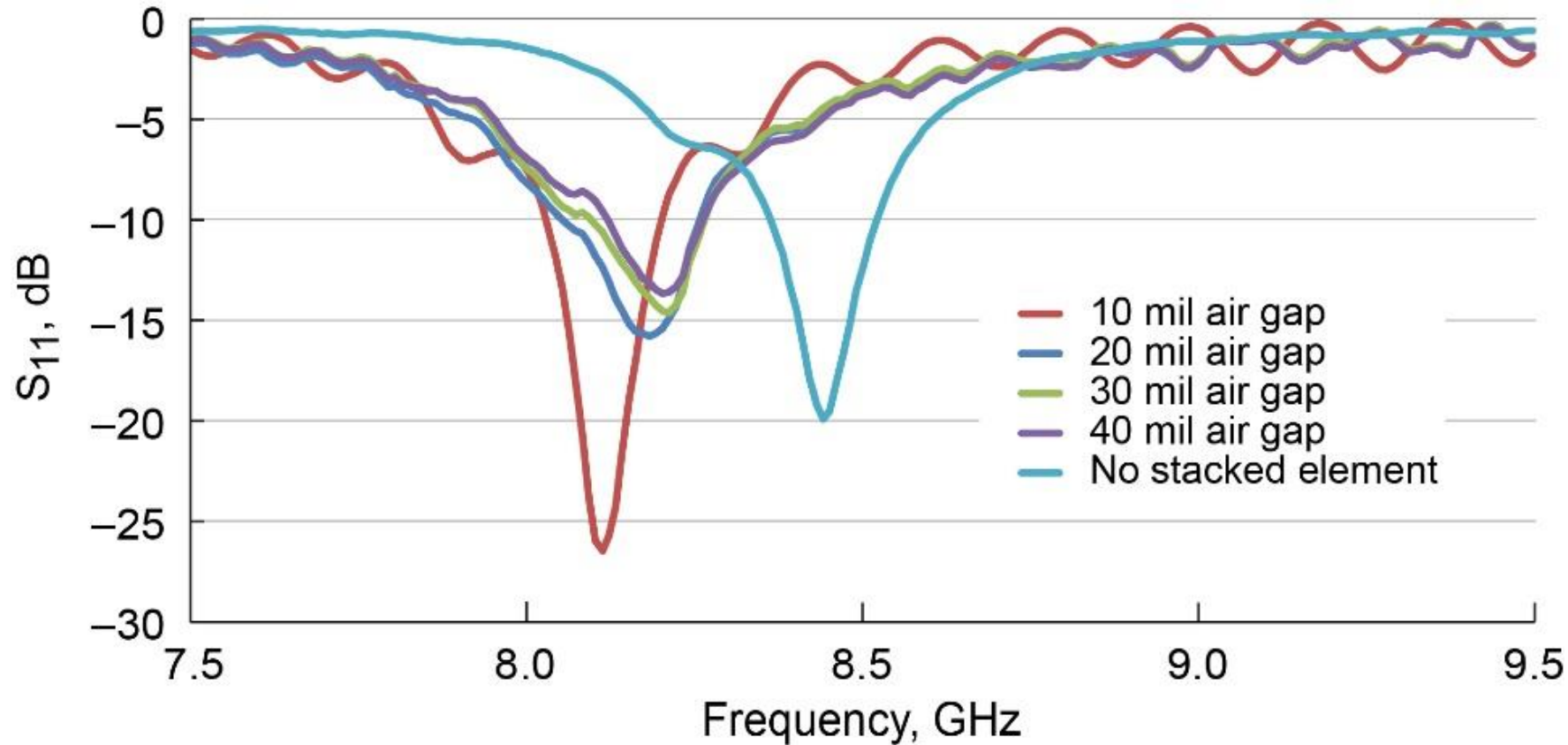
- Adding a stacked patch causes a center frequency shift due to added capacitance
- This center frequency shift is part of the frequency reconfiguration features of this antenna
- Air gap reconfiguration:
  - The initial air gap is 0.254 mm
  - The air gap can be incremented in steps of 0.254 mm
  - Experimentally, a shift in center frequency is observed in the order of 13.12 MHz per 100 microns



## Simulated Air Gap Variant



## Measured Air Gap Variant



*\*The main takeaway from this experiment is that the central frequency in a stacked square patch can be reconfigured by as much as 100MHz (Shifted from 8.1017 to 8.2017 GHz).*

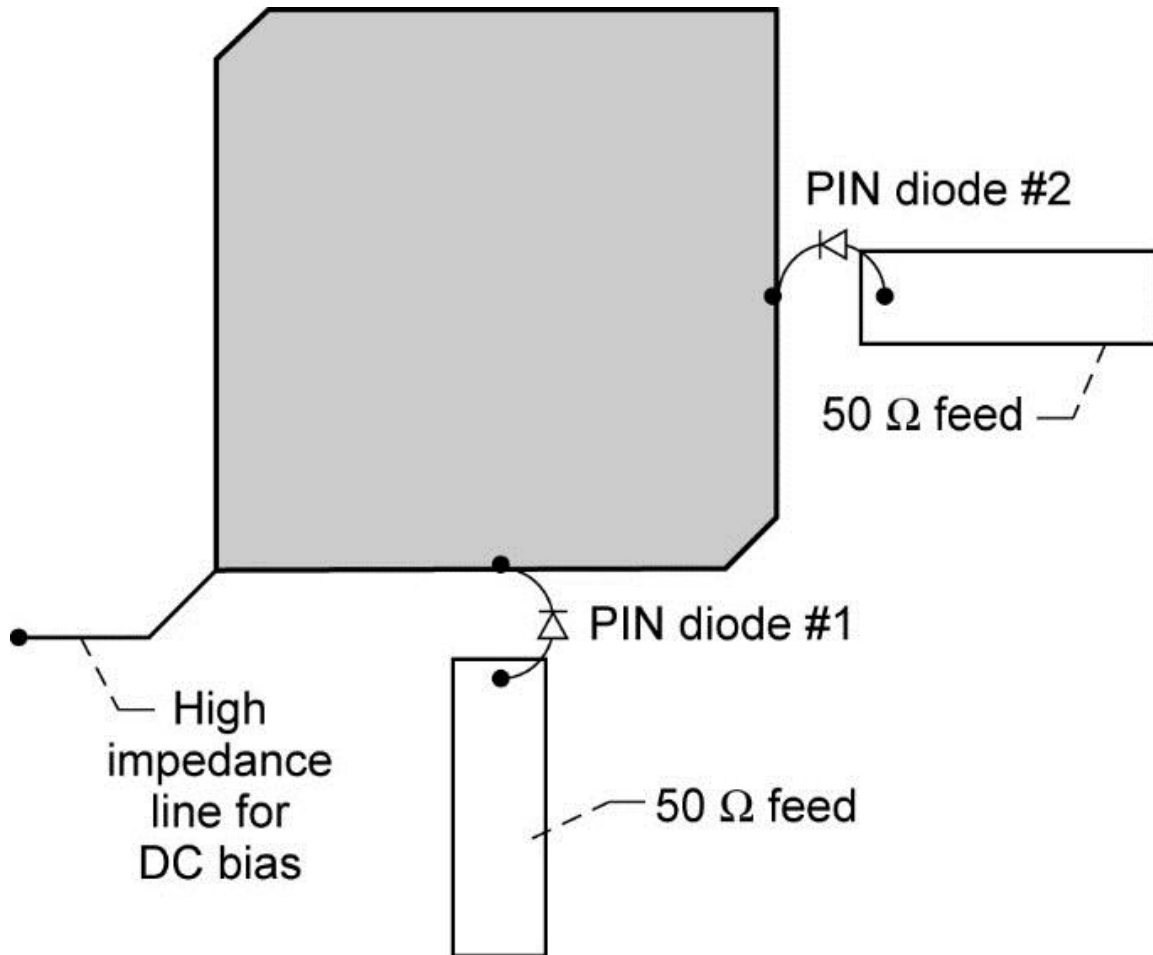


# Summary of Results



MEASURED RESULTS SUMMARY						
	$f_0$ (GHz)	Return Loss (dB)	$f_L$ (GHz)	$f_H$ (GHz)	$BW = f_H - f_L$ (MHz)	$BW/f_0$ (%)
<i>Almost Square Patch</i>	8.46	17.5402	8.385	8.529	144	1.7
<i>Square Patch</i>	8.45	19.7545	8.3675	8.5255	158	1.87
<i>Stacked Square Patch</i>	8.1017	25.7	8.0204	8.2005	180.1	2.22

	Air Gap (mil)	$f_0$ (GHz)	Return Loss (dB)	$BW = f_H - f_L$ (MHz)	$BW/f_0$ (%)
<i>Stacked SP Reconfiguration</i>	$\infty$	8.45	19.7545	158	1.87
	40	8.2017	13.68	140	1.70
	30	8.195	14.56	165	2.01
	20	8.18	15.81	205	2.51
	10	8.1017	25.7	180.1	2.22



- Polarization Reconfiguration:
  - Ability to become LHCP or RHCP.
  - PIN diodes would work as switches.
  - Integration of semiconductor devices with antenna elements.



# Future Work (Continued)



- Electronic Reconfiguration:
  - RF Microelectromechanical systems (MEMS)
    - Advantages
      - Electrostatically actuated MEMS devices consume insignificant amount of power during operation
      - Higher linearity when compared to semiconductor devices
  - Realization
    - Electro-active polymers/shape memory alloy actuators
    - Magnetic actuators
    - Displacement multipliers





# Conclusions



- The impedance bandwidth of the CP square patch antenna excited from the ground plane side by a surface launch connector is superior to the case when excited from the edge by a 50 ohm line
- When an identical patch is stacked above the driven patch two things happen:
  - The impedance bandwidth further improves
  - A center frequency shift is observed, which can be exploited in a cognitive radio
- A varying air gap further expands frequency reconfiguration capabilities
- MEMS devices can be utilized to achieve efficient frequency tuning



# Acknowledgements